RADC-TDR-63- 128

Final Report

A RADIAL FLIGHT PATH CONTROLLING SYSTEM FOR AN/ASM-13

TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR-63- 128

May 1963

Electromagnetic Vulnerability Laboratory
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

Project No. 4557

(Prepared under Contract No. AF30(602)-2803 by Bendix Corporation, Bendix Radio Division, Baltimore 4, Maryland. Author: A.E.F. Grempler)

ABSTRACT

This report is a summary of services performed by the Bendix Radio Division in developing a radial flight path controlling system for the ASM-13 antenna pattern analyzer. The report was written by the Bendix Corporation and covers the design, fabrication and installation of the system in an Air Force C-131B aircraft. Also included are the results of an acceptance test conducted at Friendship Airport, Baltimore, Maryland.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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1. INTRODUCTION

The AN/ASM-13 airborne antenna pattern analyzer has a self-contained system for the computation and recording of the aircraft's azimuth position relative to the test antenna. The basic element of this system is a doppler radar and in the case of the original AN/ASM-13 was the AN/APN-81 doppler navigator. The azimuth angle computation is made by electronically counting the doppler frequency. It is then recorded in the form of a line strobed across the antenna pattern.

Experience with the AN/ASM-13 had shown that the original concept of using a doppler navigator for the computation of azimuth position was satisfactory. However, the desirability of making automatically guided radial flights soon became apparent. Radial flight data can be used to plot vertical profiles of rotating antennas from 0 to 90 degrees, thus producing information over a greater angular range than is possible with the circular flight technique.

The AN/APN-81 doppler navigator had several disadvantages which could be ameliorated or eliminated by the installation of a more modern solid state doppler navigator. For example, the weight of the AN/APN-81 doppler navigator without spares is about 350 pounds and its power requirements necessitated the installation of an additional inverter. Another disadvantage of the AN/APN-81 is its inability to make reliable computations if the aircraft's bank angle exceeds 10 degrees. This is a serious defect in the AN/ASM-13 system when it is considered that bank angles of as high as 20 degrees are required during the course acquisition.

Another factor to be considered was that the use of the AN/APN-81 with its stabilized antenna required use of the large bathtub type radome on the belly of the C-131B aircraft. Elimination of this radome by means of a flush mounted antenna would improve the aerodynamic characteristics of the aircraft and result in more economical operation due to the reduced drag.

In order to overcome the disadvantage of the AN/APN-81 radar set as used in an aircraft with ASM-13 equipment installed, Bendix proposed to the Air Force that the installation of a modern solid state flush antenna type of radar complete with position computer would overcome or ameliorate all of the disadvantages cited above.

The doppler navigator selected for installation in the C-131B aircraft, which acts as the vehicle for the ASM-13, was the Bendix DRA-12 doppler navigator. This system is a completely solid state except for a klystron transmitting tube and utilizes a flush-mounted nonstabilized antenna. Its installation weight, less wiring and waveguide, is less than 84 pounds. Its power consumption is 1.4 amperes at 27.5 volts and 195.5 volt amperes from the aircraft's 400 cycle 117 volt source. It is anticipated that its use of solid state components will increase reliability and produce less heat. The position computer of the DRA-12 permits the generation of a control signal to be fed into the aircraft's autopilot for automatic control of the aircraft during radial flight in ASM-13 test programs. This report will describe the installation and testing of the DRA-12 doppler navigator in an aircraft with ASM-13 equipment installed.

2. INSTALLATION

The installation of the DRA-12 doppler set in the Air Force C-131B aircraft was divided into two tasks. The one task which was the installation of the flush mount antenna in a belly-hole cover supplied by the Air Force was to be accomplished by Bendix. The installation of the doppler components themselves in the aircraft along with the required wiring and waveguide runs was to be accomplished by the Flight Test Section at RADC. This operation went according to plan and was completed on schedule.

Figure 1 is a photograph of the individual doppler components exclusive of the computer. Figure 2 is a photograph showing the navigation computer and computer controller. With the exception of the INA-12A antenna, all of the components of Figures 1 and 2 were installed in the aircraft by Flight Test Section at RADC. The INA-12 indicator which reads drift angle and ground speed was installed on the instrument panel in front of the pilot's seat. The CNA-12 control was installed in the overheat control panel over the copilot's seat. The CNA-24A computer controller was installed on a specially manufactured mounting plate on the right hand side of the cockpit adjacent to the copilot's seat. The remaining components were installed in a special rack forward of the left hand pad control and aft of the entrance door in the cabin of the aircraft.

The ANA-12A antenna was installed on the belly-hole cover by Bendix. Figure 3 is a photograph of an identical antenna installed in the belly-hole cover of another C-131B aircraft. Figure 4 is an external view of the belly-hole cover installed in the aircraft with the antenna mounted. The access plate had been removed at the time of the photograph. The purpose of the access plate is to permit disconnection of the waveguide and cables to the ANA-12A antenna before removal of the belly-hole cover. A quick disconnect waveguide fitting is used to facilitate the removal of the cover when necessary.

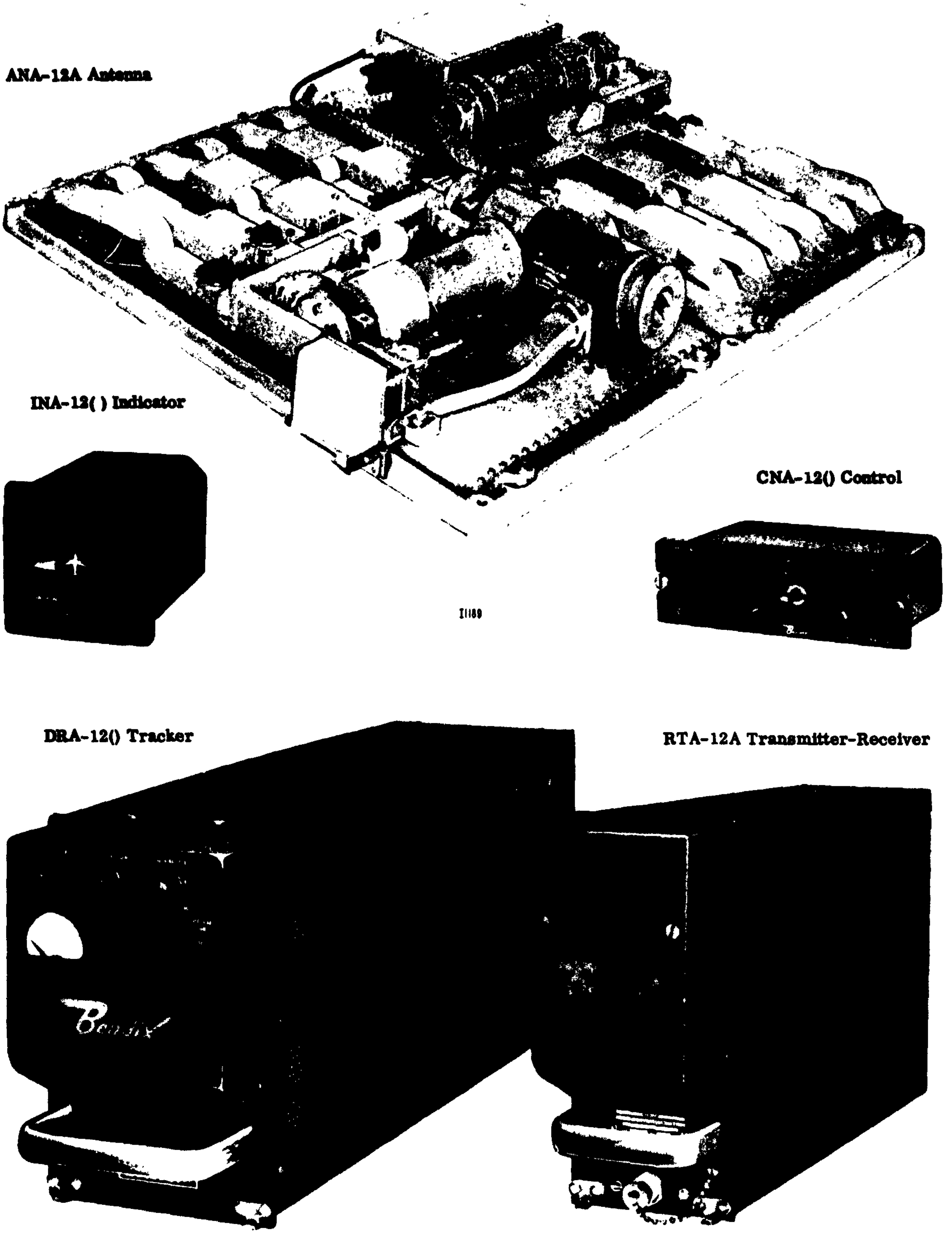
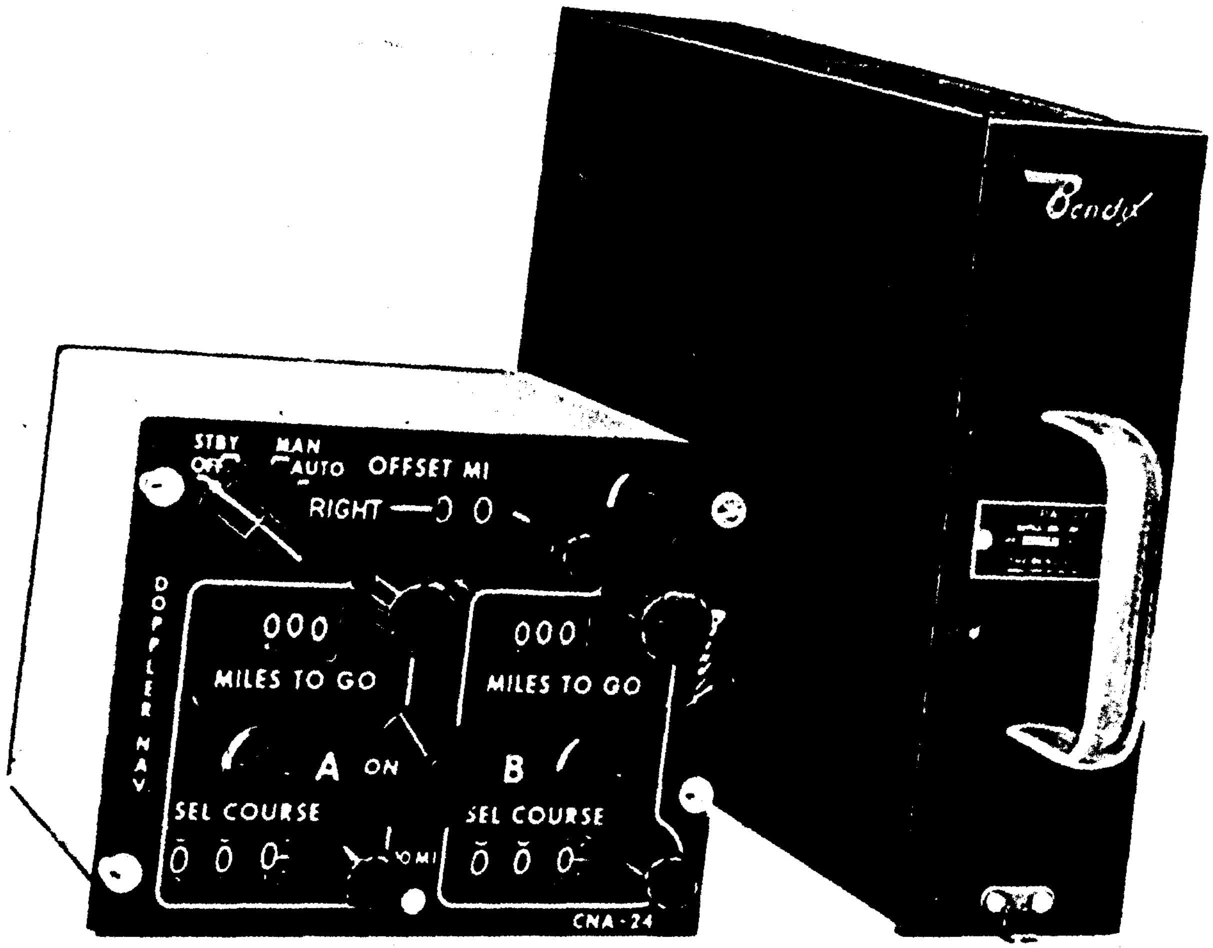


Figure 1. Photographs of Radial Flight Path Controlling System Units



CPA-24A Navigation Computer

CNA-24A, B-1 Computer Controller

Figure 2. CPA-24 Navigation Computer System

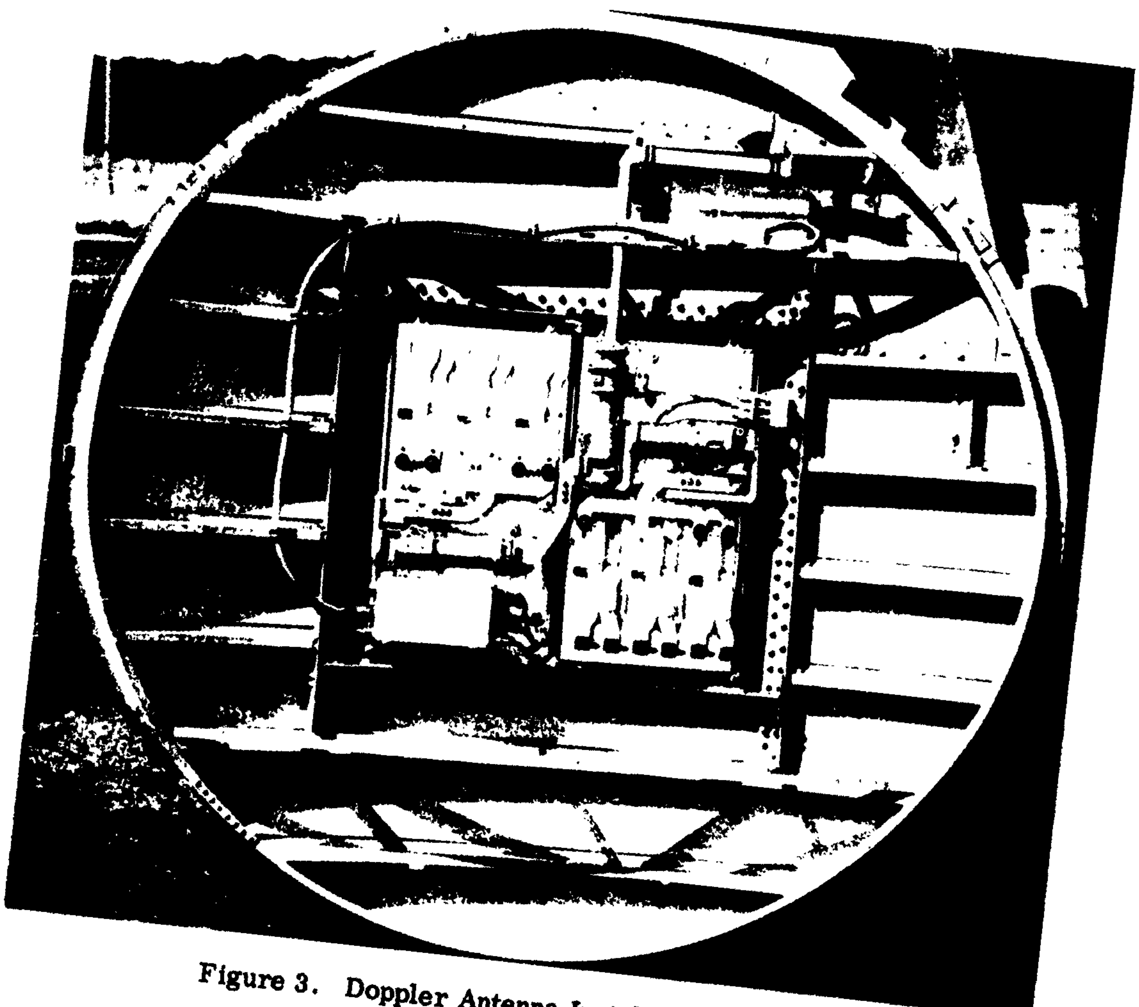


Figure 3. Doppler Antenna Installed in Belly-Hole Cover of a C-131B Aircraft

Figure 4. Flush-Mounted Radome of Doppler Antenna Installed on a C-131B Aircraft

3. MODIFICATIONS TO THE DRA-12 DOPPLER NAVIGATOR COMPUTER FOR THE AN/ASM-13

For the purposes of normal aircraft navigation, the off-course dials of the CNA-24A computer controller are designed to read 99 miles full scale. While this is satisfactory for airline and cross-country types of navigation, it is not satisfactory for maintaining the aircraft on a radial to the degree of accuracy desired in the ASM-13 system. The reason for this is that the error signal for commanding the auto-pilot to turn the aircraft is taken from a potentiometer connected to the offset-miles drive motor. In order to increase the gain of the radial flight path control system, the offset mile computer has been modified so as to read ten miles full scale when the equipment is operating in the ASM-13 radial flight path mode. This was accomplished by the addition of the circuitry shown in Figure 5. This circuitry was made necessary due to the fact that a simple gear ratio change would not have been satisfactory because of a lack of driving power, therefore, the circuitry of Figure 5 increases the resolution of the system by a factor of ten and at the same time supplies the additional power required to drive the "offset miles" readout.

An additional modification which has been made to the CPA-24A computer increases the temperature margin under which the equipment will work. This modification is necessitated by the fact that in the radial flight path mode with a 10-mile full scale readout on the offset miles indicator; the power amplifier which drives the synchronous motor which drives the cross-track stepping transmitter must operate far more frequently and rapidly than was intended in the original design. For this reason, the power dissipating or temperature tolerance of this power amplifier must be increased to prevent failure of one of the transistors in the push-pull motor driving circuit. The details of this modification are included in the Appendix.

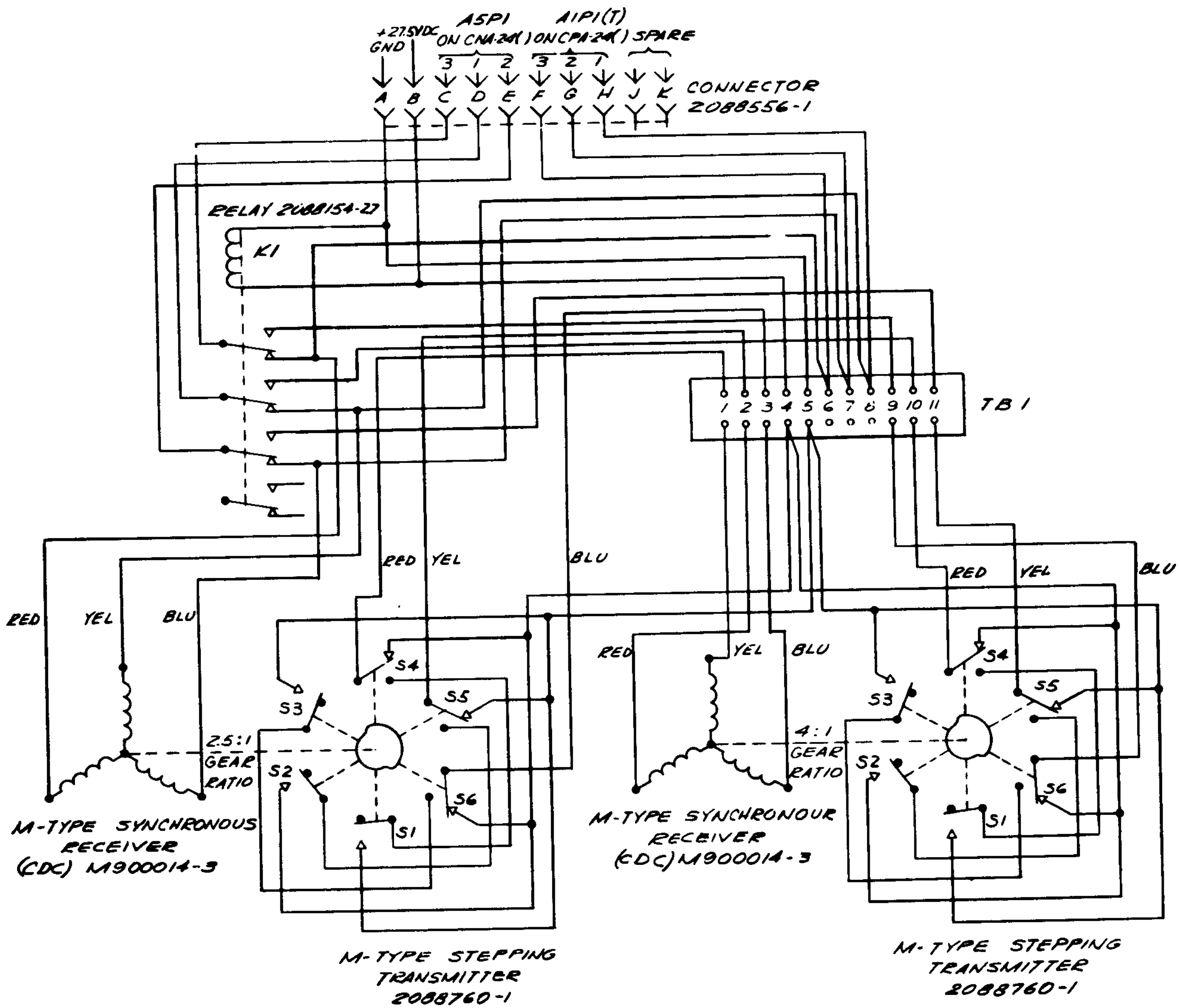


Figure 5. Schematic Diagram CPA-24B

4. USE OF THE DRA-12 DOPPLER NAVIGATOR IN THE ASM-13 SYSTEM

4.1 GENERAL

The use of the doppler navigator itself as a navigation aid in flying the aircraft and its operation in general are described in the instruction manuals supplied to the Air Force with the doppler navigator. These are Bendix publications IB1012 and IB1024A. For this reason, the operation of the doppler set itself and its maintenance and theory will not be discussed in this report.

4.2 CIRCULAR FLIGHT MODE

The DRA-12 doppler navigator is used in the ASM-13 system for circular flights in a manner identical to that in which the AN/APN-81A was used. The two principal exceptions are that the bank angle of the aircraft may be ignored up to 45 degrees and the doppler constant in cycles per foot is different. For the AN/APN-81, the doppler constant was 13.109 cycles per foot, but for the DRA-12 doppler navigator, the doppler constant is 4.76 cycles per foot. The preset doppler count is established according to the system described on page 106 of Volume 1 of the Instruction Manual for the ASM-13 antenna pattern analyzer.

Figure 6 shows the flight mode selector of the ASM-13 Doppler and Figure 7 is its schematic diagram. When the doppler navigator is used with the ASM-13 in the circular flight mode, the flight mode selector switch, (Figure 6) is moved to the "Circular" position under the "System Status ASM-13" block. It will then be properly connected to feed the doppler signal into the counter.

4.3 RADIAL FLIGHT MODE

The installation of the DRA-12 doppler navigator and computer in the ASM-13 system makes possible automatic control of the aircraft in the radial flight mode. When radial flight tests are being made, the flight mode selector switch is placed in the Cross-Country Status under Autopilot 10. This places the

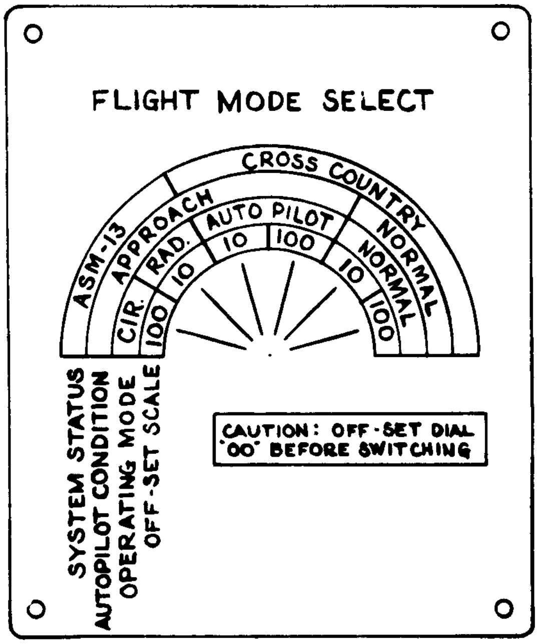


Figure 6. Front Panel ASM-13 Doppler Flight Mode Selector

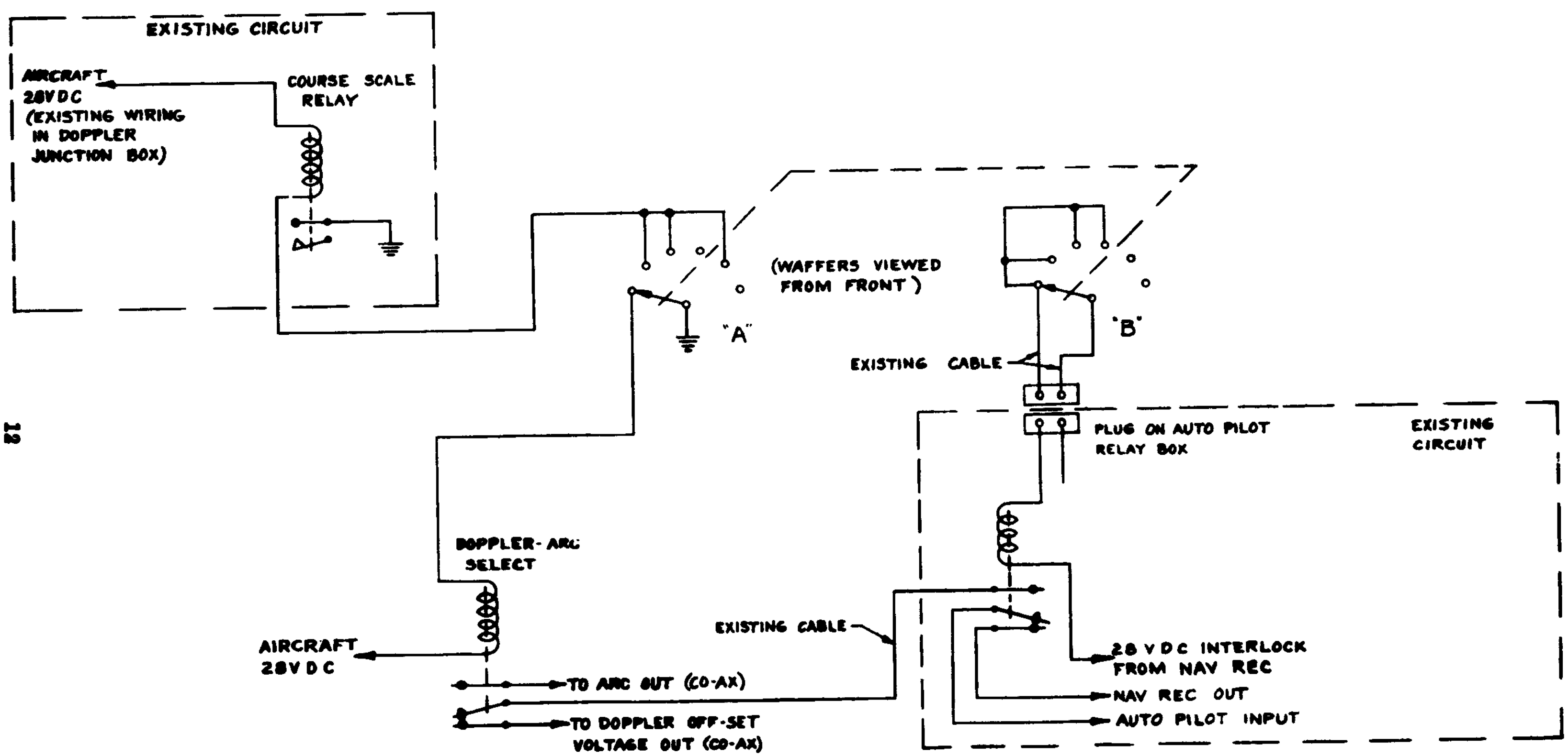


Figure 7. Schematic Diagram Flight Mode Selector

output of the autopilot off-course error signal into the approach amplifier of the autopilot. It also changes the full scale reading of the off-course dials to ten miles. The displacement and rate gains of the approach amplifier on the autopilot should be set in at least the number six position and preferably in number eight.

The technique of flying the radial course, then, is that, after having selected the correct position on the flight mode selector, the aircraft is orientated along the radial flight path to be flown by oral commands from the theodolite operator on the ground. Just as the aircraft comes over the site, as indicated by the reference tone supplied from the ground, the autopilot control switch is moved to the approach position; and, at the same time, the standby switch on the computer controller is moved to the automatic position or the manual position as may be desired. The aircraft will then proceed to continue to fly the preset radial course until the desired distance from the radar site has been flown. The distance from the site can be computed by subtracting the miles-to-go reading on the computer controller from the original setting used as the aircraft came over the site.

As the aircraft flies away from the site, it is desired to record the longitudinal distance of the aircraft from the site. In order to accomplish this function, the doppler counter is used as in circular flight and its output pulse is strobed across the antenna data in the same way. The difference is that the interval between strobes now represents linear distance traveled along the ground and not degrees of azimuth as it does in circular flight. The counter must be set so as to strobe the desired distance increment on the recording paper. This is done in a manner similar to finding the preset count for azimuth angle in the circular flight mode. The distance increment in feet which it is desired to record is multiplied by the doppler constant of 4.76 cycles per foot. This gives the preset count. For example, if on a particular recording run, it was desired to record each 2,000 feet of air travel from the site, the preset count would be 9,520. This information along with knowledge of the aircraft's altitude can be used to compute the elevation angle of the aircraft with reference to the site and it can also be used to compute the range correction required to normalize the recorded data.

5. THE FLIGHT TEST PROGRAM

A flight test program was carried out at Baltimore in order to prove that the DRA-12 doppler navigator was functioning normally and within the specifications of the ASM-13. This program was divided into three phases. Phase I was a proving program to check out the doppler navigator itself and is a routine check performed on all doppler navigator installations by Bendix. The Phase II of the test program was the demonstration of the radial flight capability of the system. Phase III of the test program was a demonstration of the circular flight capability of the system. All three phases were carried out at Baltimore, although separated by a period of several weeks due to weather and the necessity to use the ASM-13 to acquire data at Dauphin Island, Alabama in the interim. The first flight test was carried out at Baltimore on 13 September 1962. On board the aircraft were Capt. B. H. Harris, Major D. Girten, who were the pilots, Lt. Bruebaker and Mr. Battiste of RADC. Bendix personnel participating in the test were Mr. Fogarty, Mr. D. L. Reaser, Mr. A. E. F. Grempler. The first portion of the flight test was employed in a general and routine checkout of the Bendix doppler by Mr. Fogarty.

After ascertaining that the doppler was functioning correctly, some general checks were made to determine that the autopilot was not malfunctioning. After having made these tests, a radial flight was then set up between Towson test site of Bendix and the Martinsburg, West Virginia VOR station. A Washington sectional chart (December 1960) was used to select headings and to measure distances. The heading used was 276 degrees magnetic. The aircraft compass deviation was shown to be two degrees east, therefore, a compass setting of 274 degrees was set into the doppler computer. The distance to Martinsburg was 59.15 miles as taken from the sectional chart. Distance reference was a tone transmitted to the aircraft from the Bendix Towson site. At arrival over the Martinsburg WVOR, the distance to go dial indicated zero and the aircraft appeared to be offset from the VOR by 1,500 feet as agreed between Mr. Grempler, Lt. Bruebaker, and the pilots.

The specified accuracy for the radial flight path control is that course deviation shall not exceed 1.3 percent of the distance traveled. The distance from the Towson test site to the Martinsburg, West Virginia VOR is 59.15 nautical miles. The distance tolerance then is 4681.6 feet left or right of the desired course at the Martinsburg omni station. Even considering the inaccuracies which are probably contained in the aeronautical sectional chart, especially in regard to the magnetic variation, the performance of the system is seen to be well within the specified tolerances, for radial flight paths.

Upon return of the aircraft to the Towson site to commence orbital flying for testing of the circular mode performance of the doppler set, weather conditions deteriorated to the point where it was necessary to cancel the tests. A second test flight however, was undertaken on 8 October 1962 again with the aircraft based at Friendship Airport in Baltimore. The Air Force representative on board the plane was Mr. Battiste of RADC. The Bendix representatives were Mr. Grempler and Mr. Reaser. The flight test consisted of a single radial flight again to the Martinsburg VOR station to see if the performance of 13 September could be repeated and this was followed by circular flights to determine the azimuth angle of the doppler.

The flight to Martinsburg was made under the same conditions as the 13 September flight except that heading information was taken from an area chart, and could therefore be expected to be somewhat more accurate. Under these conditions, the course selected was 276.7 degrees magnetic and again the aircraft compass deviation of two degrees east was used so that 274.7 degrees was set into the doppler computer prior to flying over the Towson site. As the aircraft passed over the Towson site, the reference was supplied by a tone from the ground. On arrival at Martinsburg, the offset from the Martinsburg VOR station was 0.3 of a nautical mile, as given by the aircraft's distance measuring equipment and the distance-to-go indication was zero when the aircraft was adjacent the VOR station at Martinsburg. Since 0.3 nautical mile represents 1,824 feet, it is clear that again the system had performed well within its specified accuracy tolerance. Upon return to the Towson site, the aircraft was put into five mile orbits at an altitude of 5,440 feet which corresponds to an elevation angle of ten degrees with respect to the site. The orbit direction was counterclockwise.

The technique for measuring the accuracy of the DRA-12 doppler set in circular flight was based upon the use of the Wild theodolite which is a basic part of the ASM-13 system. After the aircraft was placed in orbit in normal fashion, a reference tone was transmitted from the ground. This started the doppler counter working and strobing 0.1-degree lines on the ASM-13 recorder paper. For checking the accuracy over the 30-degree increment from the reference tone, the ground theodolite was used to transmit a tone to the aircraft for each ten-degree increment. In most cases the aircraft was allowed to fly 40 or 50 degrees while these measurements were being made. The tones transmitted from the ground were recorded on the recording paper along with the strobe output of the electronic doppler counter. In this way, the accumulated error could be read directly from the ASM-13 recording paper. Figure 8 is a plot of the results obtained from the 30-degree tests.

For testing the 360-degree accuracy of the DRA-12 doppler in circular flight, a system identical to that described for the 30-degree angle accuracy was used except that reference tones were transmitted every 30 degrees while the aircraft completed one 360-degree flight. Figure 9 is an illustration of the results obtained.

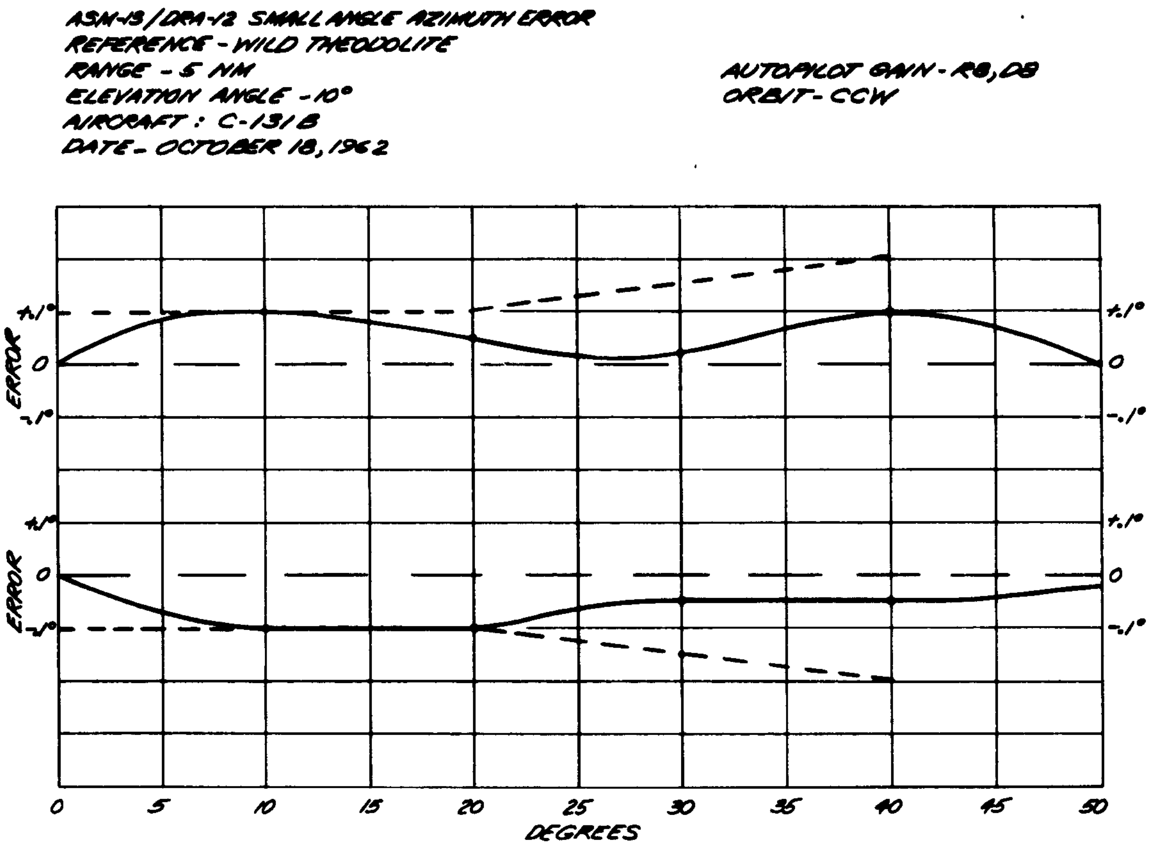


Figure 8. ASM-13/DRA-12 Small Angle Azimuth Error

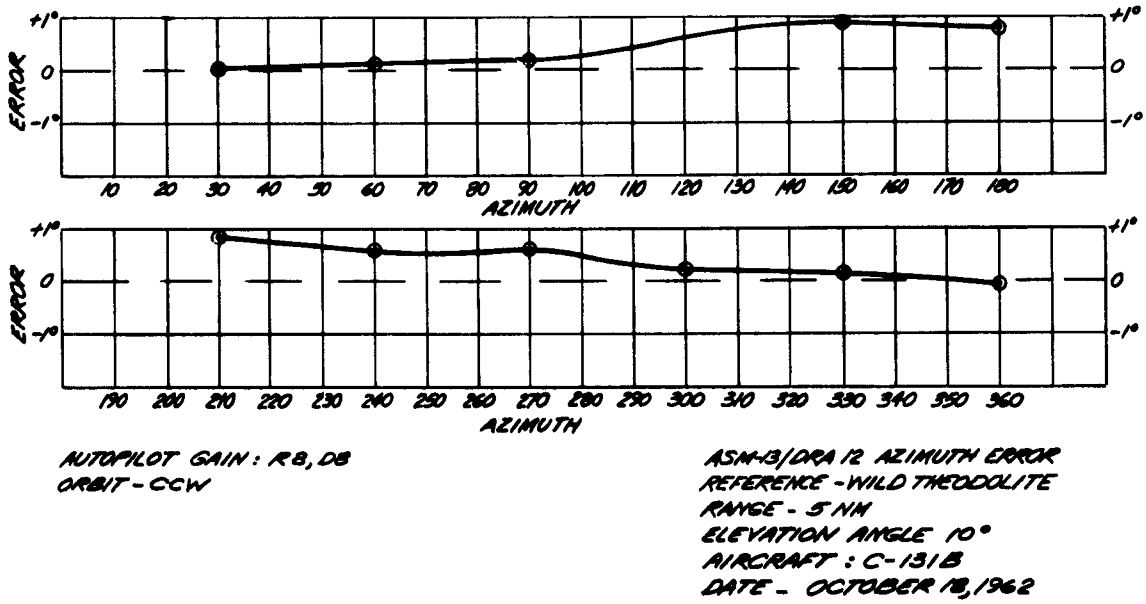


Figure 9. ASM-13/DRA-12 Azimuth Error

6. CONCLUSION

Examination of the results obtained during the test flight for both the circular and radial modes of operation indicates that the DRA-12 doppler performs the functions required of it in the ASM-13 system to a satisfactory degree of accuracy. Table 1 is a comparison of the contractually required performance and the measured performance during the flight test program, and shows in a concise and direct way the actual performance of the system.

The total weight of the radial flight path controlling system, less wire and waveguide, is about 85 pounds, a weight reduction in the aircraft of 265 pounds. Although Bendix is not qualified to give any quantitative data, it has been reported by Air Force pilots familiar with the characteristics of the C-131B aircraft that the removal of the bathtub radome has noticeably improved the performance characteristics of the aircraft. This is particularly true of its single engine characteristics. The guidance of the aircraft along the radial flight path is smooth and effortless as well as accurate, and the system has not required any modifications to the basic auto-pilot in the C-131B. The left-right signals are fed into the approach coupler as in the circular flight mode.

The velocity output of the DRA-12 doppler set has a certain amount of noise on it due to terrain variations. Because of this, there is a random variation in the position of the tenth degree strobelines. This condition can be greatly reduced by the addition of an integrator or smoothing circuit in the DRA-12 doppler. The presence of the noise on the velocity output does not bother the accuracy of the position computations of the doppler set. Since this is regarded as its most important function for the purpose for which it was originally designed, no smoothing was applied to the velocity output. Such a smoothing circuit has been developed, however, and is used in those doppler sets whose application require it. The ASM-13 would be regarded as one of those applications.

TABLE 1. SYSTEM PERFORMANCE

CIRCULAR FLIGHT		
50-DEGREE RUNS		
A. +0.055 Degree Average Error		±0.15 Degree Required by Specification
B. -0.065 Degree Average Error		
360-DEGREE RUN		
Maximum Error	0.9 Degree at 150 Degrees	±2 Degrees Required by Specification
RADIAL FLIGHT		
First Run Error	0.42 Percent	1.3 Percent Required by Specification
Second Run Error	0.51 Percent	

7. RECOMMENDATIONS

It is recommended to the Air Force that, at the first opportunity, the aircraft be removed from flight service for a day or two so that Bendix can install the smoothing circuit on the velocity readout.

APPENDIX

CPA-24B NAVIGATION COMPUTER MODIFICATION

1. Replacement of zener diode CR1 and rewiring of the bias supply.
2. Replacement of motor drive transistors Q2, Q4, and Q6.
3. Addition of a zener diode in series with the azimuth servo drivers Q202 and Q203.

A. PLANNING INFORMATION

1. Effectivity: CPA-24B Navigation Computers below serial number 1181 will not have this modification incorporated. Units that are modified in the factory will have a number 3 stamped on the rear to indicate this modification has been incorporated.

2. Reason: Dissipation of heat in the CPA-24B Computer is accomplished by convection cooling and radiation from the surface of the box. With this type of cooling the computer meets and exceeds the temperature requirements specified by FAA TSO.

However, in the event the computer is installed adjacent to "black boxes" that are cooled by the ARINC 404 system, and if the 404 cooling fails or is disrupted, normal ventilation may be unduly restricted and create an inadequate radiation environment for the computer. Since the computer relies on radiation for dissipation of heat, the temperature on the integrator board may rise beyond the compensating range of the temperature compensation circuit. The result may be one or more counter stages not "counting down" normally, causing continuous high miles - traveled readouts.

Since inadequate radiation environments may exist in some installations, three modifications can be made to the computer which will extend the temperature margin an additional 10 to 12 degrees.

These modifications are as follows:

(a) Increase in voltage available for high-temperature compensation.

(b) Replace germanium transistors Q2, Q4 and Q6 with silicon type.

(c) Reduce dissipation in servo drivers Q202 and Q203.

3. Description: To provide instructions and material required.

4. Compliance: Recommended.

5. Approval: Complies with FAA TSO C68 Cat. B.

6. Time Required: Approximately 2-1/2 hours.

B. ACCOMPLISHMENT INSTRUCTIONS:

1. Remove both side covers and the front panel.

2. Drill the .201 hole in the left side of the ball resolver and gear train mounting plate as shown in Figure A. Blow all metal chips out of the unit after drilling.

3. Mount the 15-volt zener diode IN1355A (2088336-5) on the mounting plate as shown in Figure B. Circuit symbol number will be CR8.

4. Disconnect the white-black wire from terminals 5 and 6 of the servo motor mounted above the ball resolver. Terminals 5 and 6 are connected together with bus wire.

5. Disconnect connector J1 from plug P101 on the right side of the unit. Remove the mounting screws securing plug P101 to the mounting studs, Figure C.

6. Pull the white-black wire, disconnected in step 4, back through the cable to the plug. Replace the plug and connector.

7. Connect the white-black wire to the ground lug under the zener diode installed in step 3. Solder.

8. Connect a wire (WXY 1001 P-91) to the zener diode terminal, route the wire along the existing cable, and connect it to terminals 5 and 6 on the servo motor. Solder both connections. Spot tie both wires (ref. step 7) to the cable to prevent possible interference with the gear train.

9. Disconnect the 4 wires from terminal board TB-2, which is located on the right side of the unit adjacent to potentiometers R1 and R3. Remove and discard the terminal board.

10. Disconnect and discard the above 4 wires from the integrator board connector J3.

11. Remove the integrator board from the unit.

12. Remove and discard R4, 4.7K resistor connected in parallel with thermistor RT-1.

13. Replace zener diode CR1 with a 24-volt zener IN970B (2088809-57). CR1 is mounted adjacent to capacitor C1 on the end of the board.

14. Rewire the bias supply and transformer T1 as follows:

(a) Remove the white jumper wire connected between pin 10 and pin 4 of T1. See Figure D.

(b) Disconnect the white wire from pin 11 of T1 and connect it to pin 9 of T1.

(c) Disconnect the white-brown-black wire from pin 10 of T1 and connect it to pin 4 of T1. Do not solder.

(d) Connect a jumper wire from pin 4 to pin 11 of T1. Solder both connections.

(e) Pin 10 of T1 should now be vacant.

(f) Locate terminal board TB1 behind the ball resolver. Move the white wire from terminal 3 to terminal 4.

15. Replace the motor drive transistors Q2, Q4, and Q6 located in the rear of the unit with 2N1702 (2089260-0701) type transistors. These transistors are either 2N236's or 2N1292's.

16. Stamp a number 3 on the rear of the unit to indicate this modification has been incorporated.

17. Perform an operational test of the unit.

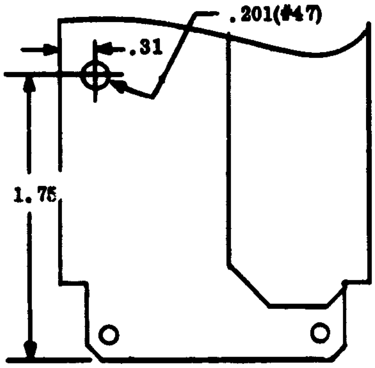


Figure A. Mounting Plate, Front View

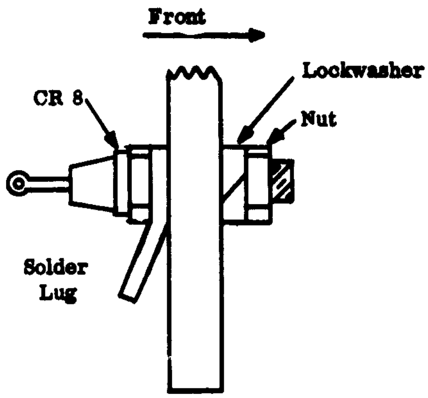


Figure B. Mounting Plate, Side View

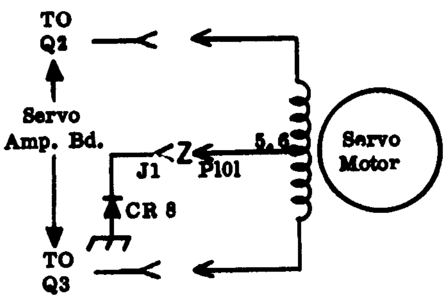


Figure C. Servo Motor Connection

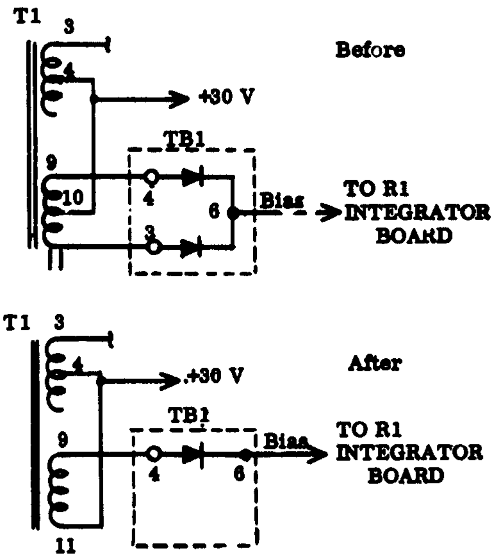


Figure D. Bias Supply

C. MATERIAL REQUIRED:

Quantity	Description	Part Number	Symbol Number
1	Zener diode, 15 volt, IN1355A	2088336-5	CR8
1	Zener diode, 24 volt, IN970B	20888909-57	CR1
3	Transistors, 2N1702	2089260-0701	Q2, Q4, Q6
10 inches	Insulated wire, white-brown	WXY 1001 P-91	

D. ORDERING INSTRUCTIONS:

These parts will be supplied on a no-charge basis if ordered within 6 months of publication date of this bulletin. Please reference Service Bulletin M-386 when ordering from:

THE BENDIX CORPORATION
Bendix Radio Division
Baltimore 4, Maryland
Attn: Avionics Spare Parts
Department 285

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II. Contract AF30(602)-2803
III. Bendix Corporation, Towson, Maryland
IV. A.E. F. Grempler
V. In DDC collection

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